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# Status and perspectives on bioenergy in Korea

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ABSTRACT

The current status of and challenges associated with bioenergy production and utilization in Korea are reviewed in this paper. Bioenergy (particularly transport biofuels) has emerged as a promising option for mitigating Korea's $CO_2$ emissions and enhancing its energy security. Korea's limited biomass resources and the high cost of biofuels are the major barriers to achieving 2030's implementation targets. Efforts to identify new suitable biomass resources for biofuels production are ongoing and intensive. Aquatic biomasses including algae and plantation wastes collected in the Southeast Asia region have been found to have great potential as feedstocks. R&D on technologies that can more efficiently convert biomass materials to biofuels also are underway. It is expected that cost-effective biofuels will be in adequate supply from 2020 and that, by 2030, their use will contribute effectively to the realization of sustainable growth in Korea.



**Contents**



## 1. Introduction

### 1.1. Energy situation in Korea

Korea consumed 0.24 billion tons of oil equivalent (toe) in 2008 and is now the 9th energy consumer and $CO_2$ emitter in the world. The major energy sources used in Korea have been fossil fuels such as oil and coal, which account for 69.0% of primary energy supply (Fig. 1). Oil accounts for about 41.6% of the total energy consumed, followed by coal, gas, and others. Since 93% of the total energy supply (and 100% of the oil) is imported, the Korean government has been actively engaged in securing the stability of the cheap energy supply that has literally fueled the high economic growth of the last several decades. However, as Korean living standards have risen, concerns about the shortcomings of fossil fuels, for example environmental issues including climate change, have grown. Recently, the Korean energy policy paradigm has been changed from "energy economy" to "environmentally friendly energy economy" (Fig. 2).

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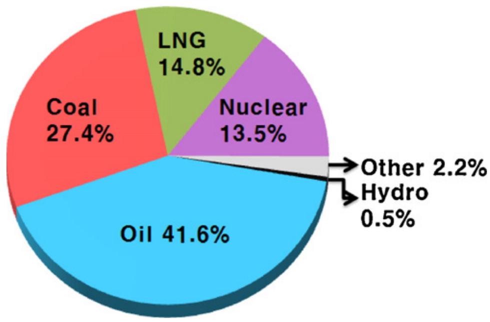


**Fig. 1.** Energy mix in Korea [1].

Nuclear power, offering excellent energy economy and low net $CO_2$ emissions, should be the first alternative energy source considered. Renewable energy, though cost inefficient, has a favorable net $CO_2$ effect, and so is also given serious consideration. Accordingly, the Ministry of Knowledge and Economy (MKE) recently announced the 2nd National Energy Plan, according to which nuclear and renewable energy will be increased markedly, from 13.5% and 2.2% in 2007 to 27.8% and 11.0% in 2030, respectively [1]. The average annual growth in renewable energy, by 2030, is projected to be about 7.8%. Correspondingly, the supply of renewable energy will be 5.7 times larger than that in 2007 (Fig. 3). Bioenergy will play a key role in this expansion of the renewable energy supply: the bioenergy supply in 2030 is projected to be $1.016 \times 10^7$ toe, 30 times greater than that in 2007 ($3.48 \times 10^6$ toe). There are many challenges to achieving the 2030 bioenergy supply target; the major issues among them are as follows:

- the high cost of bioenergy.
- limited biomass resources in Korea.
- low stakeholder-group acceptance of transport biofuels.

In this paper, major activities and R&D strategies to meet the implementation targets for bioenergy in Korea will be introduced and discussed. The work pursued in Korea could be a point of reference for countries likewise having minimal biomass resources.

### 1.2. Policy for bioenergy implementation

For most countries in the world, the high cost of bioenergy is the most important barrier to increasing its supply. As it will take

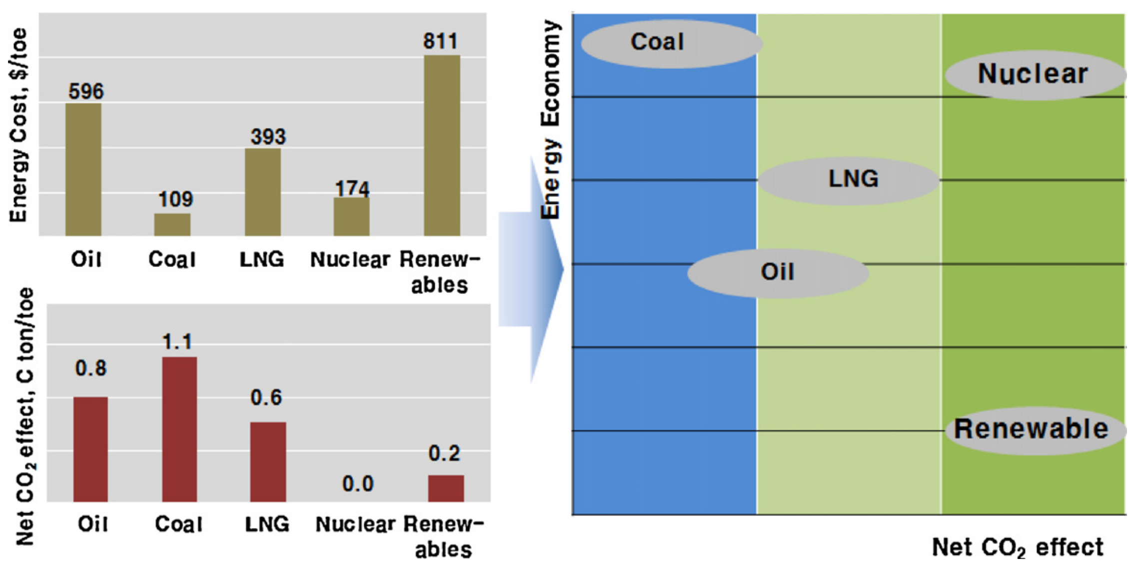


**Fig. 2.** Change of energy paradigm in Korea.

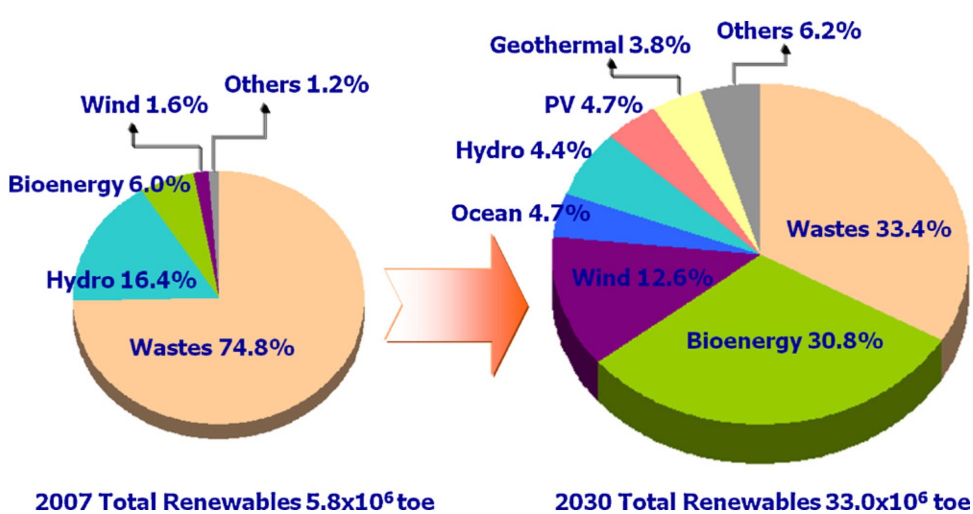


**Fig. 3.** Target for supply of renewable energies (MKE, 2008).

**Table 1**
Feed-in tariffs for bio-power in Korea.

| | Maximum capacity | Capacity | Compensation rates ($/kWh) | | Remarks |
|---|---|---|---|---|---|
| | | | Minimum baseline compensation | Feed-in tariffs | |
| | | 20 MW≤ | 0.052 | SMP[a] + 0.004 | |
| LFG | | ≤20 MW | 0.058 | SMP + 0.008 | |
| Biogas | ≤50 MW | 150 kW≤ | 0.056 | SMP + 0.008 | Fossil fuel lower than 30% |
| ≤150 kW | | | 0.066 | SMP + 0.011 | |
| Bio-power | | Wood biomass | 0.053 | SMP + 0.004 | |

[a] Standard market price of electricity in Korea.

a rather long time for bioenergy to be cost competitive in the market, various support policies for realizing the bioenergy supply are being pursued and/or followed. Korea also has instituted policy measures for the promotion of bioenergy. For power generation using bioenergy, feed-in tariffs, the rates for which are dependent on energy sources and generation capacity, have been offered since 2008 (Table 1). Feed-in tariffs are applicable only to power generation that uses less than 30% fossil fuel.

Biodiesel, the alternative to diesel oil, is fully exempted from the fossil fuel tax ($0.5/L) for cost competitiveness. As the supply of bioenergy is increased, financial problems are also incurred. For biodiesel, the deficit in 2009, when 300,000 kL of biodiesel was supplied to the country, was about 0.12 billion dollars. This shortfall, moreover, will rise when the biodiesel supply is increased to 600,000 kL in 2012. In response to this problem, the Korean government is now considering making the use of biodiesel blended fuels mandatory, in place of the tax exemption strategy. If mandatory use is realized, a similar directive for renewable fuel standards (RFS), already practiced in the USA and the EU, will be issued in Korea.

The supply of bioenergy, as stimulated by the introduction of support policies such as those just enumerated, has been steadily increased since 2004 (Fig. 4) and is expected to be continually augmented until 2030.

**Table 2**
Biomass availability in Korea [3].

| Resources | Waste biomass production ($\times 10^3$ tons/year) | Energy availability ratio (%) | Energy potential ($\times 10^3$ tons/year) |
|---|---|---|---|
| Forest residues | 6760 | 25 | 1690 |
| Agricultural residues | 571 | 25 | 143 |
| Food wastes | 170 | – | 51 |
| Municipal wastes (waste paper, woods) | 1080 | 100 | 1080 |
| Animal wastes | 1650 | 12.5 | 30 |
| Total | 10,231 | | 2994 |

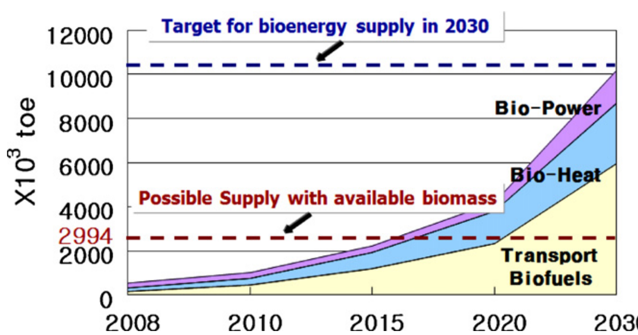


**Fig. 5.** Target for supply of bioenergies in Korea.

### 1.3. Strategy for securing stable biomass supply

The limited extent of biomass resources in Korea is another barrier to the expansion of the bioenergy supply. Although the bioenergy supply target for 2030 is about 10 million toe, the currently available biomass for bioenergy production is only 3.0 million toe (Table 2). Therefore, additional biomass resources will have to be secured to meet the implementation goal (Fig. 5). The feasibility of several options is under investigation (Fig. 6). The first candidate for bioenergy production is the currently available biomass in the country. The second option, for securing bioenergy feedstocks, is energy crop cultivation of set-aside land. In Korea, river banks and reclaimed land are available for such use. Screening of suitable set-aside lands by the Bioenergy Crop Research Center (BCRC), a subsidiary of the Rural Development Agency (RDA), has been initiated. Several strains of highly productive canola and Miscanthus have been isolated. Demonstration cultivation is already underway for rapeseed and is being planned for Miscanthus. Mass cultivation of aquatic biomasses such as micro- and macroalgae for bioenergy utilization also is under review. The projects being undertaken or pursued in Korea will be described later. The final option for securing biomass for bioenergy production is energy crop cultivation in foreign countries. Currently several Korean companies are running palm farms and/or promoting Jatropha and Eucalyptus plantations in Southeast Asian countries. With all of these efforts, the biomass required for achieving the bioenergy implementation target will be secured.

Many R&D programs on 2nd generation biofuels made from inedible biomass are supported by the Korean government.

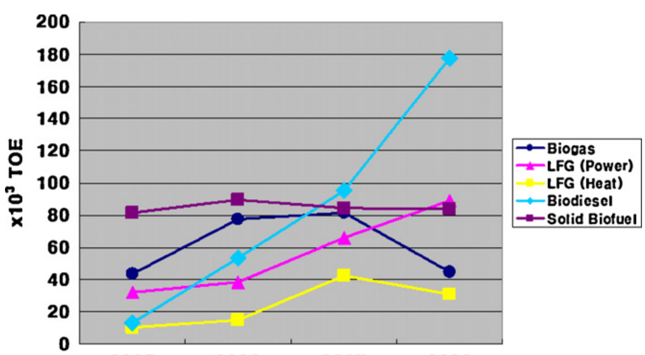


**Fig. 4.** Current aspects of bioenergy supply in Korea [2].

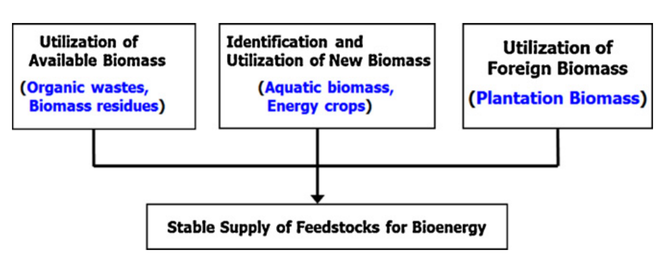


**Fig. 6.** Strategy for securing stable supply of feedstocks [3].

## 2. Current status of bioenergy supply in Korea

Since little biomass is available in Korea, intensive arguments have been made about the feasibility of bioenergy supply. After a serious process of review, the following strategy was established for development of bioenergy supply technologies. Top priority was given to bioenergy produced by utilizing organic wastes; second, to utilization of transport biofuels, and third, to solid biofuel production from forest residues.

The development and use of bioenergy in Korea will now be discussed.

### *2.1. Biogas*

The first commercialized bioenergy was biogas produced from anaerobic digestion of food wastes. In the 1990s, 15,000 tons/day of food wastes were being discharged and dumped into landfills together with other garbage, producing bad odors and very large amounts of leachate having the potential to pollute streams and underground water. Also, the atmosphere around landfill sites was becoming polluted with methane (a greenhouse gas) and chlorinated hydrocarbon gases as food wastes broke down. As Korea began to experience a shortage of landfill sites owing to its very high population and small land area, the government banned the landfilling of organic wastes, including food wastes, from 2005. However, the problem was that food wastes, since they are about 80–90% water, cannot be disposed of by conventional technologies such as incineration. In response, an anaerobic digestion process for food waste reduction that produces humus and biogas has been developed [4]. The unique characteristic of this technology is the two-phase anaerobic digestion process, which separates the acidic and biogas fermenters so that optimized conditions can be maintained for each case. Indeed, the process is tailored to the several special properties of Korean high-water-content food wastes. In 1996, a pilot-scale plant having a treatment capacity of 5 tons of food waste/day was funded, constructed and operated by Halla Engineering and Heavy Industries Ltd., in cooperation with KIER. After the successful test operation, the full commercial process, which has a 60 tons/day treatment capacity, was started up to convert food waste and cattle manure to biogas. Currently the plant produces 4800 $m^3$ of biogas daily, which is used to run a 600 kW generator. The electricity is sold to Korea Electric Power Company (KEPCO) through the public grid. Now, in addition, post-purification biogas is being trialed as fuel for compressed natural gas (CNG) vehicles.

### *2.2. Landfill gas (LFG)*

Although the landfilling of organic wastes was banned from 2005, about 1000 landfill sites remain. Landfill gas (LFG) recoverable from landfill sites, then, is another important bioenergy source in Korea. Utilization of LFG in the past was mainly for the purposes of producing heat, but now, LFG is being used as fuel for co-generation of heat and power. Currently, there are eleven LFG-to-electricity facilities, and the total installed LFG-to-electricity capacity amounts to 82.0 MW. The largest LFG-to-electricity operation not only in Korea but also in the world, with a capacity of 60 MW, is located near Metropolitan Seoul. With strong support, including feed-in tariffs, from the Korean government, power generation from LFG has steadily grown in output (Fig. 4).

### *2.3. Biodiesel*

As mentioned earlier, the importance of transport biofuels has been ignored due to their high costs. However, environmental issues including air pollution and climate change came to be important as Korean living standards increased. In 2002, air pollution over Seoul having become an important social issue, the Ministry of Environment (MOE) considered alternative fuels including CNG and biodiesel to mitigate the problem. In case of CNG supply to vehicles, a new distribution network incorporating gas refill centers will have to be established, which will require a large budget, not to mention a rather long time. So, biodiesel, which could be distributed through the established infrastructure, was recognized as the more promising option. From 2002, a demonstration supply of 20% biodiesel blended diesel oil (BD20) was initiated, for distribution through about 130 licensed gas stations in Seoul and Chonbuk province. This project faced strong opposition from car makers and oil refineries, the major stakeholder groups in the transport fuel market. These lobbies worried about the compatibility of biodiesel-blended fuels with Korean-made cars and its stability during distribution, respectively. All sports utility vehicles (SUVs) made by Korean companies are equipped with the common rail direct injection (CRDI) engine, which is very sensitive to fuel quality. To resolve these issues, a Korean biodiesel standard was instituted in 2004. The standard placed no limits on monoglyceride (MG), diglyceride (DG), triglyceride (TG) or free glycerol (FG), only on the total glycerol. Then, an evaluation of biodiesel blended fuels as motor fuels was carried out, using three different vehicle models (Table 3). Each car had been run up to 60,000 km over 2 years, from 2004 to 2006. BD20 and 5% biodiesel-blended diesel oil (BD5) were used as the fuels throughout the evaluation. From the results, it was concluded that BD5 was completely compatible with the vehicles tested but that BD20 caused some problems under cold temperature conditions, due mainly to injector clogging by solidified impurities, the major component of which was MG. Thus, in a new set of biodiesel standards (2009), limits were imposed on each unreacted component, including MG, DG, TG and FG (Table 4). This amendment brought the Korean biodiesel standard up quite close to the EU standards, EN14214. After a two-year running test, the fuel injection systems of the cars were checked, and no signs of deterioration were found.

From 2007, biodiesel producers have supplied their products to the oil refineries, and the oil refineries have been responsible for biodiesel blending and the distribution of BD5 to all gas stations in Korea (Fig. 7). Further, Korean car makers must now provide BD5-standard cars. BD20 is allowed only for fleet users having their own gas stations. To avoid problems during the winter season (1st November–13th March), the biodiesel content in BD20 was lowered to 10%. BD20 also was tested as a locomotive fuel, for 2 years from 2006 to 2008. In the results, the locomotive emitted about 20% less air pollutants compared with diesel fuel. In fact, no troubles were observed with BD20 over the entire two-year run.

From 2008 to now, biodiesel use in Korea has steadily increased; $4.0 \times 10^5$ kL is supplied in 2010, which will account for 2% of total diesel consumption. Furthermore, the 2012 and 2030 targets are $6.0 \times 10^5$ kL and $2.0 \times 10^6$ kL, respectively. As the supply of biodiesel

**Table 3**
Evaluated vehicles and fuels (2004–2006).

| SUV Brand | REXTON | SANTAFE | SORENTO |
|---|---|---|---|
| Injection system (supplier) | CRDI (Delphi Inc.) | CRDI (Bosch GmbH) | CRDI (Bosch GmbH) |
| Tested fuel | BD5 | | BD20 |

**Table 4**
New Korean biodiesel standards (no. 2009-68) [5].

| Parameter | Unit | Lower limit | Upper limit | Test method |
|---|---|---|---|---|
| Ester content | wt% | 96.5 | – | KS M 2413 |
| Flash point | °C | 120 | – | KS M 2010 |
| Viscosity at 40 °C | $mm^2/s$ | 1.9 | 5.0 | KS M 2014 |
| Carbon residue | wt% | – | 0.1 | KS M ISO 10370 |
| Sulfur content | mg/kg | – | 10 | KS M 2027 |
| Ash | wt% | – | 0.01 | KS M ISO 6245 |
| Copper corrosion at 50 °C, 3 h | | – | 1 | KS M 2018 |
| CFPP[a] | °C | – | 0 | KS M 2411 |
| Density at 15 °C | $kg/m^3$ | 860 | 900 | KS M 2002 |
| Water content | wt% | – | 0.05 | KS M ISO 12937 |
| Total contamination | mg/kg | – | 24 | EN 12662 |
| Acid value | mg KOH/g | – | 0.5 | KS M ISO 6618 |
| Total glycerol | wt% | – | 0.24 | KS M 2412 |
| Monoglycerides | wt% | – | 0.8 | KS M 2412 |
| Diglycerides | wt% | – | 0.2 | KS M 2412 |
| Triglycerides | wt% | – | 0.2 | KS M 2412 |
| Free glycerol | wt% | – | 0.02 | KS M 2412 |
| Oxidation stability at 110 °C | h | 6 | – | EN 14112 |
| Methanol content | wt% | – | 0.2 | EN 14110 |
| Alkali metals | | | | |
| Na + K | mg/kg | – | 5 | EN 14108, 14109 |
| Ca + Mg | mg/kg | – | 5 | Pr EN 14538 |
| Phosphorous content | mg/kg | – | 10 | EN 14107 |

[a] For winter, November 15–February 28.

is increased, the stable supply of raw materials becomes a more important issue. Since more than 80% of total feedstocks used for biodiesel production is imported vegetable oil, it is worthwhile to utilize the biomass resources domestically available. Used frying oils (UFO) collected from various industrial sources (200,000 tons/year) are a promising potential feedstock. Currently, some UFOs are being utilized as raw materials for cattle feedstuffs, but the rest has been disposed illegally, which threatens to cause serious environmental pollution. Recycling UFO into transportation fuels should not pose such problems. However, most waste fats contain high free fatty acid contents, the alkaline catalysts, widely used commercial catalysts, which may not be used for conversion of waste fats into biodiesel because of the low yields of the process due to the formation of soaps. In Korea since 2000, concerted effort has been made to develop an efficient biodiesel production process that utilizes waste fats. From 2006, waste cooking oil has been used as feedstock for biodiesel production. By 2009, about 50,000 tons of locally collected waste cooking oil was being used in biodiesel production. Waste cooking oil currently accounts for 17% of the total feedstocks so far used.

Another promising biodiesel feedstock is the energy crop rapeseed. According to the Rural Development Agency (RDA), Korea has about 400,000 ha of fallow farmland available for winter rapeseed cultivation. In the meantime, the RDA has developed a highly productive rapeseed strain named "Sunmang," which has an oil output of about 1500 kg/ha. This means that the annual potential output of biodiesel fuel made from winter rapeseed will reach $6.0 \times 10^5$ kL. Recently, the Korean Ministry of Agriculture initiated demonstration cultivation of rapeseed in set-aside paddy fields in order to determine its economic feasibility.

### 2.4. Bioethanol

The feasibility of the implementation of bioethanol itself, in Korea, also has been investigated. The major issue is the compatibility of the established fuel distribution infrastructure with bioethanol blended gasoline (gasohol). When the ethanol concentration in gasohol is low (less than 10%), phase separation between ethanol and gasoline can occur even with very low concentrations of water. Fuel storage tanks at gas stations, unfortunately, have no system to prevent water intake. In response to this potentially very serious problem, a demonstration study on the supply of 3% (E3) and 5% ethanol (E5) gasohols, as delivered through the currently available distribution infrastructure over the course of 1 year (mid-June 2007 to the end of July 2008) was launched [3]. From the results, it was concluded that the current fuel distribution infrastructure in Korea is fully compatible with E3 and/or E5 gasohol supply. Now the Korean government is considering when to allow the full supply of gasohols and how to support that.

### 2.5. Solid biofuel

Forestation has been actively undertaken in Korea since the beginning of the 1970s. But although abundant forest residues exist in Korea's mountains, hardly any have been utilized due to the high costs incurred in their collection. This notwithstanding, the utilization of such residues is becoming urgent as the demand for

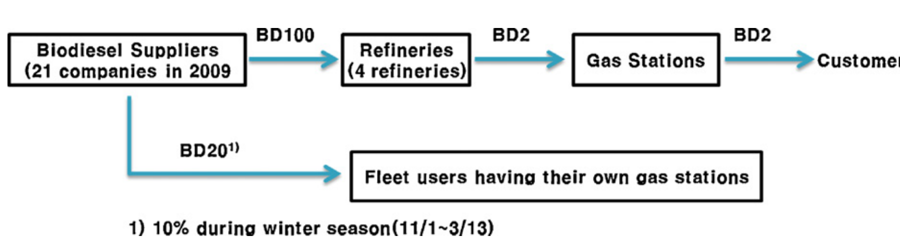


**Fig. 7.** Schematic diagram of biodiesel distribution infrastructure.

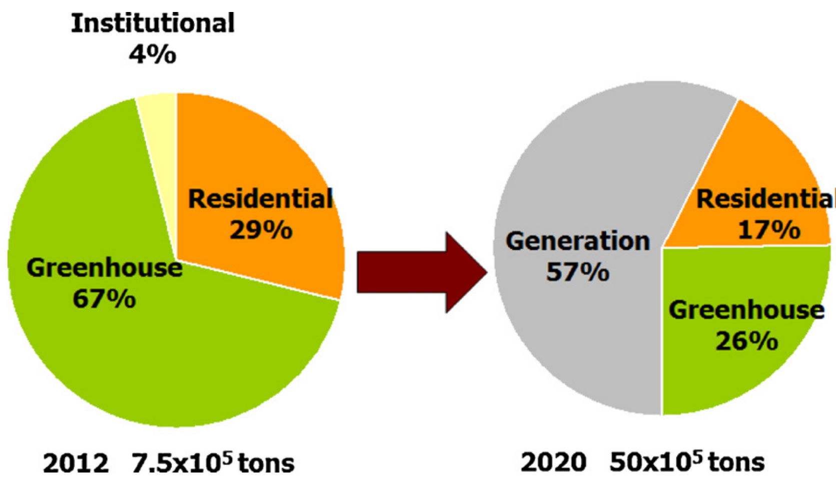


**Fig. 8.** Demand for wood pellets, Korea, 2012 and 2020 (Korea Forest Service, 2009).

bioenergy rises. Various options for use of those residues have been evaluated, and indeed, solid biofuels were determined to be the most feasible option in the short term. The Korean government, having prepared plans of action to support the implementation of solid biofuels such as wood chips and pellets, achieved, from the mid-2000s, an initial supply. Wood chips mainly have been used, though wood pellets of standardized size are becoming more common, as most modern boilers require fuel homogeneity. In 2008, there were 3 pellet mills in Korea producing about 8000 tons of pellets annually. Wood pellets are consumed mostly in greenhouses; however, a large demand is expected from thermal power plants that need to meet targets set in the renewable portfolio standards (RPS) effective from October 2010. The demand for wood pellet in Korea is expected to grow from $7.5 \times 10^5$ tons/year in 2012 to $50 \times 10^5$ tons/year in 2020 (Fig. 8). Since only a portion of the pellet demand can be supplied from the biomass resources available domestically, most of the pellets will have to be imported from abroad. Accordingly, some Korean companies are actively promoting and/or operating wood plantations in foreign countries.

## 3. R&D on next-generation biofuels

In Korea, transport biofuels are very important to energy security and $CO_2$ reduction, but the current biofuels suffer from poor cost competitiveness and feedstock supply instability. To overcome these problems, next-generation biofuels need to be developed. Active R&D has been conducted to develop suitable technologies for such energy sources, including cellulosic liquid and algal biofuels.

### *3.1. Cellulosic liquid biofuels*

As in other countries, biochemical and thermochemical technologies for conversion of lignocellulosic biomasses into liquid biofuels are under development in Korea. As regards biochemical conversion, R&D is focused on bioethanol and biobutanol, which are gasoline-alternative fuels. Since the Korean work on cellulosic ethanol has already been noted elsewhere [3], only the biobutanol research will be discussed here. Korean oil refineries currently are actively working to develop butanol technology, owing to biobutanol's desirable fuel properties relative to ethanol, which include low water miscibility, low vapor pressure and high energy value. Development of genetically modified microorganisms having high butanol fermentation efficiencies, and a low-energy-consuming butanol purification technology, are the project's major targets. A pilot process producing 100 L of butanol daily from herbaceous plants including agricultural residues will be in operation by 2012.

Concerning efforts to develop a thermochemical cellulosic-biomass conversion technology, the Fischer–Tropsch process, which can produce diesel-alternative fuel, is the major accomplishment thus far. By 2013, a pilot plant capable of producing 0.1 ton of F-T diesel/day will be running.

### *3.2. Algal bioethanol*

Macroalgae entail several advantages including no need for land, a high biomass yield, and easier fractionation and hydrolysis due to the lack of any lining such as that exists for cellulosic biomasses [6]. Due to their high cultivation yield, red algae have a higher energy yield than any land plants [7]. Some research has been conducted to develop a technology for conversion of red algae (*Gelidium amamsii*) to ethanol [8,9]. If the project appears to be promising, a pilot process of 4 kL ethanol/day capacity will be underway by 2012. Since feedstock supply stability is another important issue surrounding commercialization of algal ethanol, a demonstration project for mass algae cultivation and harvesting also will be carried out. If these technology development and feedstock stability projects are successful, algal ethanol likely will prove to be cost competitive with gasoline in the market.

### *3.3. Algal biodiesel*

Microalgae are yet another possible biomass resource for bioenergy production in Korea. Research, which has been steady for some time, recently has accelerated. Because microalgae were earmarked mainly for industrial flue gas production, screening of the most suitable algal strain had to be undertaken first [10]. In due course, a strain capable of directly fixing $CO_2$ from flue gases was isolated [11,12]. Now, extensive studies are underway to optimize the culturing conditions for maximizing algal cells' oil productivity, and development of a scaled-up photobioreactor, oil extraction technology and a fuel conversion process also has been initiated [13].

## 4. Conclusions

Due to the high cost of bioenergy and the limited availability of biomass resources in Korea, little bioenergy has actually been supplied. Recently, bioenergy has been recognized as a promising tool, both for lessening Korea's dependence on foreign energy and for

$CO_2$ mitigation. An ambitious action plan for increasing the supply of bioenergy has been prepared by the Korean government. According to the plan, the supply will be increased by a factor of 30 within 20 years. Of this, transport biofuels will take the lion's share.

Again, the high cost of bioenergy and the securing of a stable supply of feedstocks are the two major barriers to expanding the bioenergy supply in Korea. The bioenergy support policies enforced in Korea, feed-in tariffs and tax exemptions, have their limits. For example, the national tax revenue deficit associated with biodiesel implementation is going to be about 20 million dollars this year. This shortfall would be increased as the future supply of biofuels is expanded. Therefore, the Korean government is considering a change in policy, from tax exemption to mandatory use. Since the latter policy also would cause a rise of fuel prices in the market, .it might not be the final solution. The best solution might be production of biofuels that are cost competitive with the conventional, petro fuels.

Limited biomass availability is the other barrier to increasing the bioenergy supply. Potential biomass resources currently available in Korea can cover only 23% of the 2030 implementation target. To solve this dilemma, a systematic approach is now being taken to secure a stable feedstock supply that meets such targets. The approach involves not only the utilization of domestically available biomasses such as organic wastes and forest residues but also new, never-before-considered biomass residues including energy crops like winter rapeseed and Miscanthus, aquatic biomasses, micro- and macroalgae, and plantation residues. In order to realize mass production of those feedstocks, demonstration projects for mass cultivation of winter rapeseed and macroalgae are ongoing.

Active research also is targeted at making biofuels commercially viable, which is to say, making it cost competitive with petro fuels. These efforts include improvements to the feedstocks supply chain as well as conversion technology enhancements and advances, particularly as focused on the nonconventional feedstocks mentioned above. Biofuels are expected to be securely cost competitive by 2020. If so, Korea might yet achieve its 2030 bioenergy implementation target.

## Acknowledgement

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